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The Future Organization of Danish Electricity Market for Integrating DERs - a View of FlexPower Project

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***Abstract*—This paper presents a view of the Danish FlexPower project to reform the existing electricity market by coordinating vast Distributed Energy Resources (DERs) for integration in future scenarios. Aiming to maximize the preservation of the existing market structure, Aggregator, the key player in mobilizing small-scale DERs to participate in the existing electricity market, is proposed in this paper to cope with the day-ahead, intra-day and regulating power market. Possible future organizations of different time-scale markets are also introduced and discussed with the precise roles and responsibilities of Aggregator. It is seen that the most appropriate function for Aggregator's capabilities is to cluster DERs as an expended ancillary service. In addition, the interactions with current market actors are introduced in detail.**

***Index Terms*-- electricity market; DERs; Aggregator; ancillary service**

I. INTRODUCTION

Over the last decade, the Danish government has conducted policies to provide incentives for the development of renewable energy technologies. Among these technologies, wind power has become the focus for a large amount of research and innovation. At the end of 2012, energy from wind power had already met 30% of Danish annual electricity consumption [1]. Moreover, Government policy has targeted a 30% wind power share of total energy consumption and 50% of electricity consumption by 2025 [2]. Denmark is on its way to extricating itself from traditional energy consumption and to releasing its dependence on fossil fuels by 2050 [3][4].

Considering the increasing penetration of renewable energy sources into existing and future electricity market structures, there is a great challenge for system operators in maintaining system security and reliability. The stochastic and fluctuant nature of wind power requires a sufficient regulating power operation to ensure system balance between electricity production and consumption. To avoid unnecessary overburden of interconnection cables which import regulating power when needed in Denmark, DERs are put forward as a new type of regulating power source which is planned to generate electricity from small-scale renewable power generation or to change electricity portfolios in consumption [5].

The arising conflicts between DERs and outdated market structures are the most essential reason for improving the existing market structure so as to adapt to the new electricity industry environment and to promote a more efficient and effective power system. In particular, these conflicts include: a) Only Central Generation (CG) is taken into consideration in the design of electricity market structures, and the incentives from DERs are not considered comprehensively. b) Existing market rules restrict small-scale energy generation to power existing electricity markets. Therefore, the flexibility of DERs cannot be fully and effectively utilized to benefit the power system operation with high penetration of renewable energy resources.

This paper will put DER incentives as the first priority when designing new market structures. Along with the new market actor, Aggregator, DERs will have a positive effect on maintaining system balance. However, they also need to be provided proper incentives to participate in various time-scale electricity markets. This paper intends to utilize all the advantages of Aggregator-based small scale DERs with minimal changes to the existing market structure.

The rest of the paper is organized as follows: section 2 provides some basic background information: introduction of existing electricity market, capability and economic benefits of DERs, functions of one-way price signals, and Aggregator entering into the operation of power systems. Section 3 analyzes types of possible future electricity market and ancillary service market in Denmark plus designs the interplays of each market in future organization. Finally, in section 4 conclusions and recommendations are drawn up.

II. MOTIVATION AND FEASIBILITY

A. *Existing Market*

In the Nordic countries, the electricity trading market is Nord Pool Spot, in which the Day-ahead market and intra-day market are the two major market places for trading electricity. before operation: (1) The Day-ahead market trades electricity by auction and closes one day before operation and (2) the

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intra-day market trades electricity in the form of bilateral contracts and closes one-hour before operation [6].

Within the operating time, the Transmission System Operator (TSO) maintains and restores system balance between production and consumption through power bought previously in the reserve capacity market by automatically controlled reserve devices. Moreover, the regulating power market is under the operation of the TSO by activating bids for the manual reserve that was traded previously in the reserve capacity market, or any other bids for voluntary regulating power. Moreover, other reserve capacity works automatically in response to frequency deviations so as to conduct regulation at an earlier time than the manual reserve [7].

B. Economic Benefit of DERs

DERs may refer to a few types of generation that are plausible for providing flexible energy for the power system. Typical examples of these generations include Wind Turbines, Electric Vehicles (EV), Heat Pumps and Solar Cells, etc. [8]. With the growing share of DERs in total electricity production, DERs' contribution in grid stability and operational security will keep increasing through substituting part of the power from CGs. Compared with CGs, DERs may have advantages in quick response as well as short-distance electricity supply to end-users because of its flexibility due to small scale.

DERs' potential ability to provide certain ancillary services has been the focus of much literature, for example [9]. Principally, DERs are capable of providing any ancillary services, provided the DERs can meet the output requirement of the ancillary service.

The cost of DERs' generation is another essential concern in determining whether or not to select DERs as a reserve provider to CGs. In fact, DERs are relatively cheap, with lower installation costs and apparently lower variable costs than CGs. Lower variable costs mean a low incremental cost of each kWh electricity. Hence, electricity from DERs has a high price advantage in providing energy as well as reserve capacity.

C. One-way price signal

With the help of advanced information and control technology, it is possible to utilize the flexibility of DERs to provide regulating power in regulation market through receiving and reacting price signals. The main idea of this price-based signal control method is introduced in [12]. This concept focuses on a one-way price signal method, which is a supplement of the current regulating power market.

D. Aggregator

Generally, the Balance Responsible Party (BRP) has a duty to register and report all generation data. With the entry bidding requirement of BRPs, the arising DERs cannot be directly connected with BRPs in existing market organizations. To overcome this, a new market actor, Aggregator, is proposed and designed to mobilize these DERs in order to satisfy the capacity limit of entering the market. Moreover, in the FlexPower project [13], a mathematic model is formulated to simulate the response of these individuals when Aggregator is applied. The literature [13] also proves that it is more accurate to predict total output and input with the application of Aggregators, than to predict individual output and input. This means that forecasting the aggregated output of DERs or even consumption of flexible consumers, is reasonable and feasible in principle. This justifies the implementation of Aggregators as a potential therapy.

Moreover, with the integration of EVs and other electric devices in the future, end-users can change their consumption profiles accordingly. Therefore it is more challenging to predict hourly electricity profiles for Aggregators than for current normal retailers. In construction, it is the price signal that provides incentive for DERs to adjust electricity profiles. This means Aggregators should possess the ability to tackle the complex relation between price and predicted electricity profiles through historical data and weather forecasting information.

Based on this idea, BRPs are still responsible for registering and trading in market activities. However Aggregators are applied to cluster DERs and forecast total consumption or generation by them, and then consolidate data and forward them to BRPs. In the new organization, Aggregators are selected as commercial agents. Through active promotion of business deals, Aggregators engage in DERs and act as agencies between them and BRPs.

III. FUTURE ELECTRICITY MARKET DESIGN

Considering the Danish electricity market is a part of the Nordic electricity market, which consists mainly of day-ahead market, intra-day market, reserve capacity market (ancillary service market) and regulating power market corresponding to different time spans. To illustrate the market organization design, this section is divided into two parts; electricity energy market and reserve capacity market.

A. Future Electricity Market

With the development of DERs, the current market organization may become less efficient and effective. Therefore, potential improvement of the market organization in future is analyzed in this section. Moreover, a possible market structure, roles and responsibilities of market actors as well as their interactions in the future market are characterized in detail.

1) Day-ahead Market

In addition to CGs and retailers, new market participants and DERs are planning to enter the operation of power system [14]. In order to provide proper incentives for them to trade their energy in the day-ahead market, market organization should be updated. One thing that should be noted is that DERs are normally limited in capacity; therefore they cannot participate in the day-ahead market directly. Furthermore, they do not have the full ability to estimate their individual electricity input or output accurately [8], so they cannot join BRPs for trading in the day-ahead market, either. In this case, Aggregators are applied which justify the redesign of market organization.

In Figure 1, the same as the existing day-ahead market, the TSO is responsible for supervising and facilitating market activities, and there are several BRPs trading in this market [15]. In detail, BRPs forecast total generated volume and corresponding cost of their generation, as well as the total consumed volume demanded and corresponding price offered by their retailers in an individual hour of an operation day through information exchanging with retailers and CGs [6].

In this organization design, the day-ahead electricity market has more commercial actors, including retailers, CGs and also Aggregators, as shown in Figure 1. These commercial actors are allowed to share one common BRP. Aggregators, retailers and CGs forecast their consumption or production and send their schedules to their BRPs. Specifically, the new market actors - the Aggregators - forecast consumption or production of their DERs.

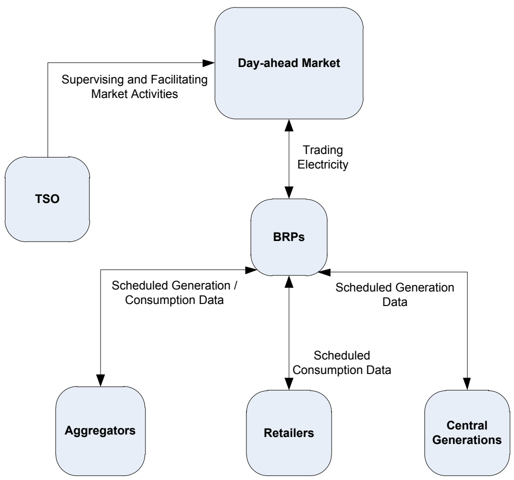

Figure 1 Interplay of market actors in the future day-ahead market

According to reported forecasts, BRPs calculate an energy volume that they will sell or purchase in the electricity market, and then send hourly bids or offers to the Nord Pool Spot day-ahead market before it closes. After Nord Pool Spot announces the spot price and bid volume of each BRP for each hour of an operation day, according to the volume it has been bid for, the BRP sends a generation plan to its CGs and Aggregators of DERs. At the same time, the BRP also sends a consumption plan to retailers and Aggregators of flexible consumers. Finally, the Aggregator can send hourly consumption price signals to DERs. One thing that must be noted here is that the generation price or consumption price of the same Aggregator may be different, even if they have the same energy spot price, because different electricity tariffs are added for electricity generation or consumption.

As shown in Figure 1, BRPs trade electricity in the day-ahead market for their CGs, retailers and even Aggregators. They are responsible for payments and income transfers. They are also responsible for the costs due to deviations of bids and offers in actual production and consumption taking place during operation.

2) *Intra-day Market*

The development and future existence of DERs in the electricity market also necessitates that Aggregators participate in the intra-day market so as to allow small-scale generators or consumers to have access to the intra-day market to trade the deviation of forecasted consumption or generation. The role of Aggregators is similar to that in the day-ahead market. Actually, the introduction of Aggregators into the intra-day market is a supplementary idea of the introduction of them into the day-ahead market.

After the day-ahead market closes, and one hour before of operation hour, BRPs may encounter unforeseeable changes in demand and generation through information exchange with retailers and CGs, as shown in Figure 2. Like other commercial actors, to maximally avoid costs from imbalanced clearing, Aggregators need to participate in the intra-day market in case deviations of estimations of their DERs happen one hour before operating time. These participations require BRPs acting as middle agencies. The TSO is still responsible for supervising and facilitating market activities

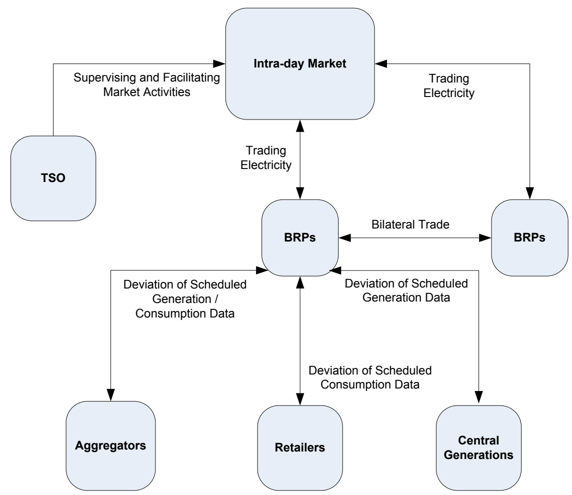

Figure 2 Interplay of market actors in current intra-day market

As shown in Figure 2, BRPs trade their deviations of scheduled consumption or generation in the intra-day market. As with the existing market, there are two kinds of trading in the intra-day market: (1) a BRP can send a request with passive or negative volume and a hidden price for a specific duration of the operation day to market, and then other BRPs can bid for it. The first BRP providing a satisfactory price will get the bid; and (2) a BRP can also directly conduct a bilateral trade with another BRP without any market activity [6]. Moreover, BRPs are responsible for payment and income transfers. They are also responsible for the costs due to imbalances in actual production and consumption during operation.

3) *Regulating Power Market*

With the development of renewable energy in Denmark, together with the policy of eliminating traditional generation, there will be an increasing demand for regulating power. Since in the case of Denmark it is the import from CGs of neighboring countries that fills the gap between requested regulating power and domestically generated regulating power [5], the burden on interconnection cables will inevitably increase. To minimize dependence on other countries and also to maintain a stable power system operation, developing own regulating power in Denmark is the most essential motivation of DERs. This in return requires an update of the organization of regulating power market so as to provide accessibility and incentive for DERs to join.

From the perspective of the TSO, with more fluctuating renewable energy generations being connected, the electricity produced by DERs will become an important source of regulating energy in the new market organization. Certainly the TSO will benefit from the flexible production of DERs when regulating energy is scarce in market. In regulating market when regulating power is required, the TSO directly cooperates with Aggregators who can directly communicate with DERs. Finally, the TSO should also be responsible for the updates of the electricity market design in response to changes in market development.

Generally, all electricity trading transactions should pass through BRPs, and all regulating power bids sent into various electricity markets are conducted by BRPs. However, since in Denmark the bidding size of regulating power is between 10 MW and 50 MW [5], it is not practical for DERs to join the regulating power market directly. Aggregators are also useful in this market. Aggregators are allowed to bid in regulating power market and act as a potential client for TSOs via BRPs. As illustrated in [13], forecasting collected generation of DERs and consumption of flexible consumers with relevance to price is reasonable and feasible in principle. Hence, in future, Aggregators should be developed to have the responsibility to bill and send various incentive signals, such as price, to DERs. Through these signals, Aggregators can manipulate the consumption or production profile when the TSO requires regulating power. Under the command of the TSO, Aggregators can also cooperate in tackling the issue of energy imbalance. Moreover, the most important point is such that with the introduction of Aggregators, advantages of DERs can be utilized and further expanded.

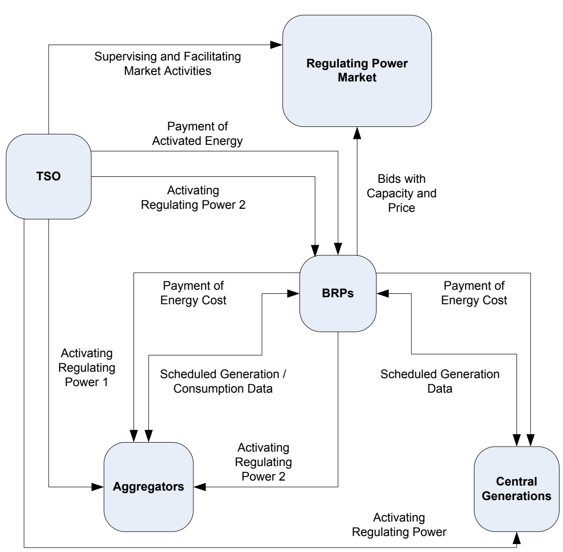

Figure 3 Interplay of market actors in future regulating power market

Like the traditional regulating power market, by regulating the power market as well as other markets for automatic reserves, the TSO maintains the balance of electricity production and consumption. The TSO implements up- or down- regulation of electricity generation or consumption by purchasing reserves power. Among all reserves, only the manual reserve needs to be activated by the TSO in regulating power market. BRPs reserved in the manual reserve market have the responsibility to send bids to the regulating power market, but other BRPs can also send voluntary bids. As shown in Figure 3, BRPs send bids with offered capacity and the price of the activating power to the regulating power market (Nordic Operation Information System). The TSO manages the activation of regulating power, and directly sends control signals to the CGs of accepted bids, as shown in Figure 3.

In this designed organization, Aggregators are applied to assemble DERs to join a BRP. If DERs under Aggregators want to join the regulating power market, they must be able to be fully activated within 15 minutes. In the regulating power market, the main task of Aggregators is to supply a promised regulating power to BRPs, and to be activated if the TSO requires regulating power to balance electricity during operation. In Figure 3, an activation order started from the TSO can be directly transmitted to power suppliers, Aggregators or CGs. Alternatively, it also can be transmitted to BRPs and then forwarded to Aggregators, as shown by arrows "Activating Regulating Power 2".

BRPs sell regulating power to the TSO in the regulating power market, so they are responsible for payment and income transfers and then Aggregators and CGs receive benefits from the BRPs, as shown in Figure 3. Costs associated with activating regulating power will be passed to those BRPs who feature imbalance [7].

B. *Future Ancillary Service Market*

Given DERs entering into electricity system, the newly designed organization should hit the following targets: 1) Aim at efficiently utilizing the flexibility of DERs to provide ancillary services for contributing to system balance. 2) Previously introduced Aggregators in future energy market will be extended to apply in the reserve capacity market, so as to have a larger capacity in bids by aggregating DERs.

The TSO purchases reserve capacity, either of consumption or of generation (measured in MW), to ensure there are sufficient DERs working to balance the electricity market. If DERs can fulfill the requirement for various reserves in response time, they can also provide these reserves with the help of Aggregators.

Whenever CGs or Aggregators provide the primary reserve, secondary reserve, and manual reserve, their BRPs are responsible for sending bids to the reserve capacity market before different reserve capacity markets are closed, as shown in Figure 4. Moreover, these generations must be approved in advance by the TSO to ensure that they have the qualification to provide reserve capacity service. After the markets have closed, the TSO announces the accepted bids and agreed price as shown in Figure 4. Then, according to the agreed price, the TSO releases payment to the BRPs.

Various reserves differ in control relation. According to [7], the primary reserve is activated by control equipment in response to grid frequency deviation; the secondary reserve is activated by a control signal from the TSO through the BRPs, which are also subject to frequency deviation; finally, manual reserve is directly activated by the TSO in the regulating power market.

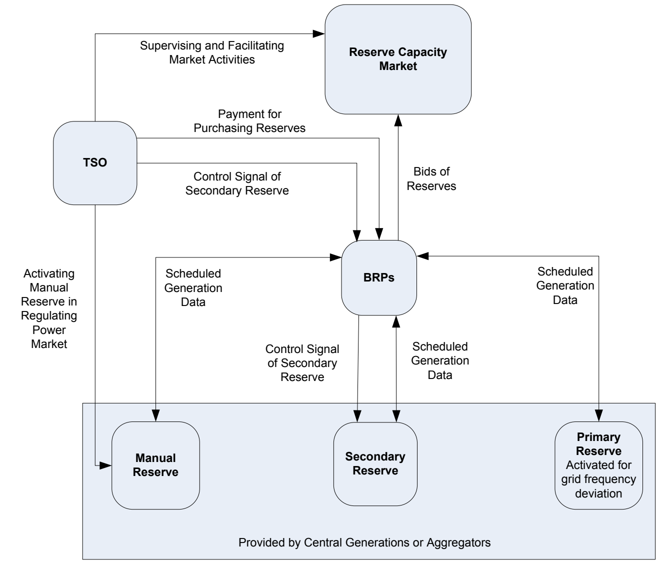

Figure 4 Interplay of market actors in future reserve capacity market

BRPs trade reserve capacity in the electricity market. They are responsible for payments and incomes transfers with the TSO. There is only an availability payment, but no energy payment of the primary reserve. The secondary reserve and manual reserve have both an availability payment and energy payment [7].

IV. Conclusion

The most satisfactory features of this proposed organization are such that with the introduction of new actors, i.e. Aggregators, (1) only slight changes are enough for market operation; (2) Aggregators are compatible with other commercial actors in operation and (3) Aggregators can provide the most efficient incentive for DER owners to join the energy market. In addition, the concept of Aggregator proposed in this paper is highly theoretical. In practice, it is critical to understand who is acting as the Aggregator. Hence, the organization could be improved in future if it is known who the Aggregator is. Moreover, in response to this, incentive schemes for the underlying organizations should take this into consideration and result in a much more complex market organization.

This paper analyzes the inefficiency of the existing market organization considering the introduction of DERs, and proposes a potential future organization and interactions with the electricity market in which the Aggregator arises to collect the DERs so as to have access to BRPs. The proposed organization and interaction can release the burden on BRPs in coping with the large amount of DERs. Moreover, in response to the ability of DERs to provide ancillary services, this report also provides a detail analysis of existing and proposed future organization and interaction of market actors in the ancillary service market. With this proposed organization and interaction of the electricity market, stable operation and development of the electricity market in the future can be ensured.

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